Reliable fat suppression in multiple-mouse imaging with a Dixon technique

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Introduction

Murine models of disease are invaluable tools for the development and evaluation of new therapies and techniques. However, obtaining statistically significant measurements via small animal imaging experiments can require many subjects, each of which may be scanned multiple times. To alleviate these challenges, the total experiment time may be reduced, not only by the use of fast pulse sequences, but also by imaging multiple animals simultaneously(1,2).

We have previously developed a simple apparatus for multiple mouse magnetic resonance imaging (MMMRI), consisting of an array of four volume radiofrequency (RF) resonators(1). One complication of MMMRI, as noted there and elsewhere(2), is that each of the volumes may have a distinct frequency distribution, making uniform shimming of the animals challenging. This may limit the effectiveness of chemical saturation-based fat suppression, which depends on the absolute resonance frequency of lipid (3). Dixon techniques are not subject to this limitation because the rely upon a relative phase difference(4), and as such they may be useful for fat suppression in multi-animal imaging. In this work we show that fat suppression in MMMRI may be accomplished with an easily implemented two-point Dixon method. Uniform suppression was demonstrated in four animals that were scanned simultaneously with a RARE-based sequence.

Methods

All data acquisition was performed in a 4.7 T, 40-cm bore Bruker Biospec MRI system (Bruker Biospin MRI, Billerica, MA, USA). All animals were cared for in accordance with Public Health Services Policy on the Humane Care and Use of Laboratory Animals. All experiments and procedures were approved by our Institutional Animal Care and Use Committee, which is accredited by the Association for the Assessment and Accreditation of Laboratory Animal Care International.

Imaging was performed with a RARE sequence, modified to allow acquisition with the read gradient centered slightly off of the spin-echo. Although this implementation does slightly lengthen the required echo train duration and can reduce slice coverage, at 4.7T the required time shift is only 0.7 ms (5). A two-point Dixon protocol with in-phase (IP) and opposed-phase (OP) images was used. The two images may be written as

$$S_{IP} = (W + F)e^{i\phi} \quad S_{OP} = (W - F)e^{i(\phi+\theta)}$$

where *W* represents the signal arising from water and *F* represents the net lipid signal. The φ term is easily removed by using the IP image as a reference. The residual phase was estimated from the OP image by fitting the phase to a third-order polynomial, as in (6), and removed. While more robust phase correction algorithms are available, this method has the advantage of being very easy to implement (and can be done automatically on Biospec consoles). One additional step is required, however, because the correction algorithm assumes that the average phase of the image is zero. This condition may cause the IP and OP images to have a different reference point for phase. A common reference point was chosen by modulating the phase of the OP image by the value which minimizes the imaginary component OP image when demodulated voxel-wise by the phase of the IP image.

Four nude mice were imaged using the linear coil array and the modified RARE sequence. The acquisition parameters were: TE/TR = 55/5000 ms, FOV = 4 cm x 3 cm, acquisition matrix = 256x192, and NEX = 2 (i.e., two IP acquisitions and two OP acquisitions). For comparison, a chemical saturation image, which used an identical protocol (except that NEX =4), was also acquired. The shim values were determined using solely the data from the first channel, and those shim values were used on all four channels. Of the three shimming techniques that were tested in the previous work, this is the fastest process, although not the most robust(1).

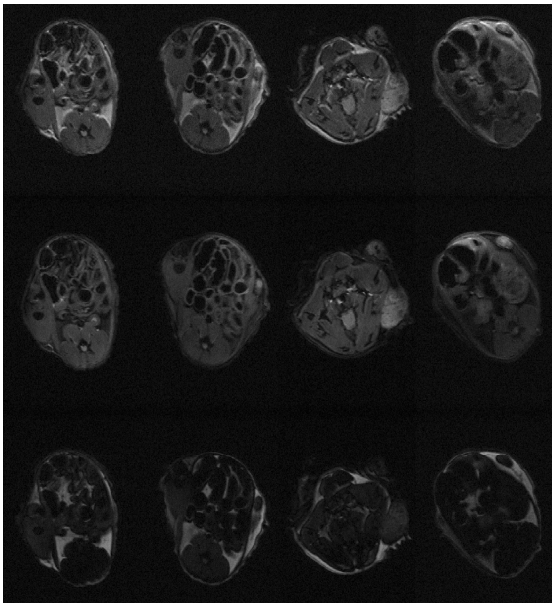

Figure 1: In-phase (equivalent to an image without fat suppression), water-only, and fat-only images from one slice of the Dixon acquisition are shown.

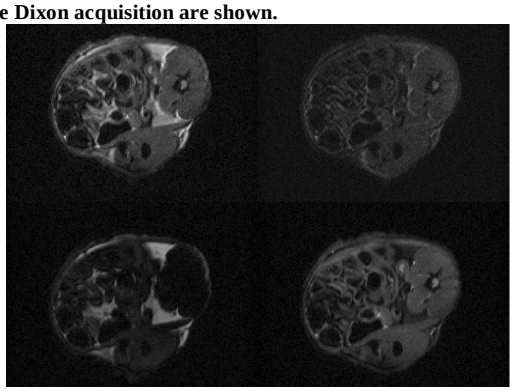

Figure 2: The in-phase, chemical saturation, fat-only, and water-only images from a selected mouse are

Results

Figure 1 shows in-phase, fat- and water-only images from each mouse. In the fourth mouse, a tumor whose boundary with the surrounding lipid is obscured becomes clearly visible in the water-only image. Figure 2 shows same-slice, same-mouse images taken from one of the mice which was not used as a reference for the shimming. Comparison of the in-phase image with the separate fat-only and water-only images shows good separation of the two species. Some residual signal can be seen in the fat-only image; this is possibly a result of the crude phase correction algorithm used. Comparing the water-only Dixon image with the chemical saturation image shows that the Dixon image has markedly better SNR, in spite of the fact that the two images had the same acquisition times. This could be attributed to an accidental suppression of the water-signal in the chemical saturation image.

Discussion

In this work we have shown that effective fat suppression can be achieved without the use of time-consuming shimming methods in our multi-animal imaging system. The phase correction algorithm is a simple extension of software available on the scanner and allows for a straightforward implementation. Dixon techniques are highly insensitive to shimming and center frequency. Chemical saturation techniques may fail leaving a degraded image—and multi-volume imaging may be particularly susceptible to this effect, due its challenging shimming and multiple center frequencies.

References

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